

Binder Effects on Water Stability and Feeding Preference in Artificial Diets for Swamp Eel (*Monopterus albus*)

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ABSTRACT

The development of stable and palatable artificial feed remains a major challenge in the culture of Asian swamp eel (*Monopterus albus*), mainly due to the continued reliance on natural feeds such as earthworms. This study evaluated the effects of different binder types and concentrations on feed stability and eel feeding responses using pasta feed formulations combining commercial pellets and earthworms. The experiment applied a factorial Completely Randomized Design involving four binder types—gelatin, gluten, carboxymethyl cellulose, and chitosan—with several concentration levels (10%, 15%, and 20%) including a control without binder. Feed stability was assessed through water immersion tests measuring feed disintegration and structural deformation, while feeding behavior was evaluated through approach frequency, consumption, rejection behavior, and feeding latency. The results showed that binder incorporation significantly improved feed stability compared with the control treatment. Chitosan at a 10% concentration provided the best resistance to feed breakage, whereas 10% of carboxymethyl cellulose, gluten, and chitosan, maintained feed structure effectively during immersion. Binder-containing feeds, particularly those with gelatin, gluten, and chitosan, exhibited no different in feeding acceptance. These findings demonstrate that optimizing binder type and concentration can improve feed stability and feeding efficiency, supporting the development of more sustainable artificial feeds for swamp eel aquaculture.

INTRODUCTION

Eel (*Monopterus albus*) represents an important aquaculture commodity with considerable economic and nutritional value in many Asian markets. The species is widely appreciated for its distinctive taste and high nutritional content, which contribute to its premium market status. In Indonesia, the domestic price of eel can reach approximately 70,000 IDR per kilogram, while export markets may reach around 300,000 IDR per kilogram,

highlighting its strong commercial potential. Globally, eel production is increasingly shaped by aquaculture expansion due to declining recruitment of wild stocks and growing demand in international markets (Yuan *et al.*, 2021). These conditions have encouraged intensified research on sustainable production systems and feed management strategies to support eel cultivation. Eels are recognized as protein-rich aquatic animals with substantial fat and energy content, characteristics that support their high-value status in both Asian and European seafood markets (Akamad, 2026; Yuan *et al.*, 2021).

In recent decades, the global eel industry has experienced substantial transformation as natural populations decline and farming activities expand to meet market demand. Asian countries dominate eel aquaculture production, yet the industry continues to face several structural constraints related to seed availability, feed supply, and technological development (Yuan *et al.*, 2021). For mud eel (*Monopterus albus*) specifically, aquaculture development remains limited in several regions despite increasing interest from farmers and consumers. Studies indicate that the sector is still developing in countries such as Bangladesh and India, where emphasis remains on improving seed production and strengthening market linkages to expand commercial culture (Mely *et al.*, 2025). These conditions reflect broader challenges within eel aquaculture, where supply chain constraints, investment requirements, and regulatory pressures influence industry growth (Mely *et al.*, 2025; Yuan *et al.*, 2021).

One of the critical challenges in eel farming relates to feed availability and cost. Feed represents the dominant operational cost in aquaculture production systems, and fluctuations in ingredient availability often influence economic viability. Across eel farming systems, limited access to high-quality protein sources can significantly increase feed prices while reducing feed efficiency. In many traditional eel farming systems, natural feed remains the primary nutritional source for cultured animals. Farmers frequently rely on earthworms, particularly red earthworms (*Lumbricus rubellus*), as a natural feed ingredient due to their high protein content and favorable amino acid composition. Earthworms are widely recognized as nutrient-rich organisms containing substantial crude protein, essential amino acids, and lipid fractions that support fish growth and health. Mashuri *et al.* (2012) reported that among several feed types—*Tubifex*, snails, fish, and pellets—earthworms produced the best growth performance. However, a study by Zaenal *et al.* (2025a) reported that earthworms are still more preferred by eels.

Despite these advantages, dependence on natural feed sources such as earthworms presents several practical limitations. The supply of earthworms is often inconsistent and relatively expensive, creating difficulties for farmers seeking to expand production. Artificial feed formulations have therefore been developed to supplement or partially replace natural feed sources in eel culture. However, one major limitation of artificial pasta feed is its weak physical structure, which often results in rapid disintegration when exposed to water. Such instability can cause nutrient leaching, reduced feed intake, and decreased feeding efficiency.

Feed binders have been widely recognized as essential components in aquaculture feed formulation because they enhance pellet cohesion, structural strength, and water stability. Binders reduce feed fragmentation during handling and limit nutrient loss through leaching in aquatic environments, thereby improving feed utilization efficiency. In aquaculture systems where feeds are exposed to water for extended periods, mechanical durability and water resistance are particularly important. Previous research has demonstrated that binder inclusion can improve pellet integrity, minimize feed crumble, and stabilize extruded feed formulations used for aquatic species (Gómez-Limia *et al.*, 2021; Rachmawati *et al.*, 2025;

Sasongko *et al.*, 2023). Furthermore, the effectiveness of binders depends on their chemical properties, concentration, and interactions with other feed ingredients.

Several natural and synthetic binders have been evaluated for their application in aquaculture feed formulations. Gelatin and gluten, for example, are commonly used as natural binding agents that improve pellet cohesion and reduce feed dust during processing. Their effectiveness depends on interactions between protein matrices and other feed components, which influence the structural integrity of feed particles (Febrianta & Rawendra, 2019; Gómez-Limia *et al.*, 2021). Meanwhile, carboxymethyl cellulose (CMC) and chitosan have attracted increasing attention due to their film-forming and gelling properties.

Comparative studies across aquaculture species suggest that the optimal binder type and concentration vary depending on feed formulation, species feeding behavior, and culture environment. Excessive binder inclusion may negatively affect palatability or nutrient availability, while insufficient amounts may fail to provide adequate feed stability. Consequently, determining the appropriate binder type and dosage is essential to achieve a balance between feed durability and feeding acceptance (Febrianta & Rawendra, 2019). However, despite increasing interest in aquaculture feed technology, research focusing specifically on binder optimization for swamp eel (*Monopterus albus*) remains limited. Quantitative comparisons among commonly used binders in eel feed formulations are still scarce, indicating the need for species-specific experimental studies.

Based on these considerations, this study aimed to evaluate the effects of several feed binders—gelatin, gluten, carboxymethyl cellulose (CMC), and chitosan—on the physical stability and feeding acceptance of pasta feed for eel (*Monopterus albus*). The research examined different binder concentrations to determine the formulation capable of producing feed with improved resistance to disintegration while maintaining acceptable feeding responses. By identifying the most effective binder type and dosage, the study seeks to provide practical guidance for developing stable and cost-efficient feed formulations that can support sustainable eel aquaculture production.

METHODS

This study was conducted from 17 May to 17 June 2024 at the Fish Nutrition and Technology Laboratory, University of Mataram, Indonesia. The study employed an experimental method using a factorial Completely Randomized Design (CRD) to evaluate the influence of binder type and binder concentration on feed stability and eel feeding acceptance.

In this study, two experimental factors were evaluated: binder type and binder dosage. Five binder treatments were included in the experiment, consisting of a control treatment without binder (K), gelatin (Ge), gluten (Gl), carboxymethyl cellulose (CMC), and chitosan (Ch). Each binder treatment was tested at four dosage levels: 0%, 10%, 15%, and 20%. Each treatment combination was replicated four times to ensure statistical reliability of the experimental results.

Following the feed stability evaluation, the feed formulation that demonstrated the highest physical stability was further tested for feed acceptance by eels. The feeding preference test used a Completely Randomized Design consisting of five treatments and twenty replications, resulting in a total of one hundred experimental units. Feeding preference experiments commonly use replicated randomized treatments to minimize bias and to evaluate differences in feeding response among feed formulations.

Container Preparation

The feed stability test was conducted using glass jars measuring 10 cm in height, 10 cm in width, and 10 cm in length. The jars were randomly labeled according to treatment groups and filled with 700 ml of water. Feed samples from each treatment were subsequently immersed in the jars to observe their resistance to breakage and deformation when exposed to water.

The feed acceptance experiment was conducted using a tarpaulin-lined concrete pond measuring 200 × 100 × 50 cm. Shelters made of raffia rope were installed inside the pond to provide hiding structures for the eels, which helped reduce stress and mimic natural habitat conditions during acclimatization and feeding observations.

Preparation of Experimental Feed

The experimental feed was prepared using commercial pellet feed (HI PRO VITE 781-1) as the primary ingredient. The pellets were first ground using a blender and then sieved to obtain a fine and uniform texture suitable for pasta feed preparation. Earthworms are used as an attractant in feed (Abidin, Lumbessy, Lestari, *et al.*, 2025). Red earthworms were crushed and incorporated into the feed mixture at a proportion of 25% of the total feed composition in each treatment.

Binder materials consisting of gelatin, gluten, CMC, and chitosan were added to the feed mixture according to the predetermined treatment concentrations of 10%, 15%, and 20%, while the control treatment contained no binder. After mixing the feed ingredients with water, the feed was formed into a pasta for stability testing and feeding trials. The detailed composition of each feed formulation is presented in Table 1.

Table 1. The Feed Composition

No	Binder	Dose (%)	Earthworm (g)	Pellets (g)	Binders (g)	Water (ml)
1	Control (K)	-	1.25	3.75	-	7.5
2	Gelatin (Ge)	10	1.25	3.25	0.5	7.5
		15	1.25	3	0.75	11.25
		20	1.25	2.75	1	15
3	Gluten (G)	10	1.25	3.25	0.5	7.5
		15	1.25	3	0.75	11.25
		20	1.25	2.75	1	15
4	CMC (C)	10	1.25	3.25	0.5	5
		15	1.25	3	0.75	7.5
		20	1.25	2.75	1	10
5	Chitosan (Ki)	10	1.25	3.25	0.5	7.5
		15	1.25	3	0.75	11.25
		20	1.25	2.75	1	15

Eel Eel Rearing

The eels were reared for 32 days. The eels used in this study had a length of 5–10 cm, with a total of 25 individuals. During the adaptation period, the eels were fed earthworms once a day in the afternoon at 16:00. The eels were reared in clear water with a water depth of 15 cm. Siphoning and a 10% water exchange were carried out daily.

Feed Stability Measurement

Each labeled container was filled with different pasta feed according to the predetermined treatments. The feed was molded into elongated shapes measuring 1 cm in

length. The containers were shaken every 5 minutes, and the physical condition of the feed was subsequently observed. The observed changes included feed breakage and loss of structural integrity. The time at which these changes occurred was recorded.

Feed Acceptance Measurement

The feeds used as treatments were those with the highest stability for each binder type. Each feed was molded into elongated shapes and randomly placed in the rearing pond. The observed eel responses included the number of eels approaching the feed, consuming the feed, regurgitating the feed, and rejecting the feed. Observations were carried out using an infrared camera. The experiment was conducted 20 times.

Data Analysis

Data obtained from the feed stability test and feed consumption observations were first processed descriptively by categorizing feed conditions and eel behavioral responses. Subsequently, statistical analysis was performed to determine differences among treatment groups. The Kruskal–Wallis non-parametric test was used to evaluate in feed stability and feed acceptance responses among treatments. When significant differences were detected, further analysis was conducted using the Mann–Whitney U test to compare specific treatment pairs.

RESULTS

Feed Stability Test

Feed stability was evaluated by observing the physical integrity of pasta feed after immersion in water, focusing on two key parameters: broken feed stability and shapeless feed stability. The broken feed stability results demonstrated clear differences among treatments and binder concentrations. Figure 1 illustrates the average time required for feed to disintegrate when exposed to water under different binder treatments and dosage levels (0%, 10%, 15%, and 20%).

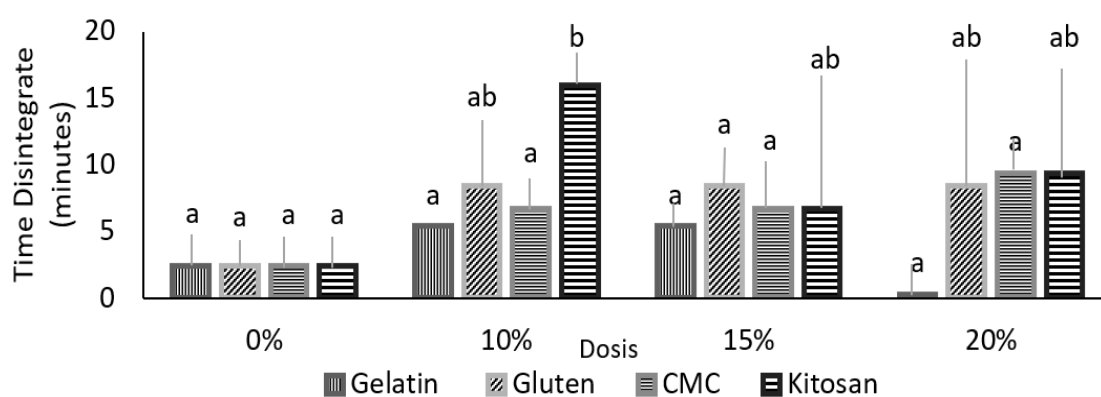


Figure 1. Feed Disintegrated Time

In the control treatment (0% binder), the feed exhibited relatively low resistance to disintegration. Average disintegration time remained approximately no more than 4 minutes for all the feed without binder, indicating that feed structure without binding agents is highly vulnerable to water exposure.

At the 10% binder concentration, stability increased substantially for chitosan ($p < 0.05$) and decrease at the 15% and 20%. Gelatin, gluten, and CMC at inclusion levels of 10–20% resulted in similar feed stability ($p > 0.05$).

The shapeless feed stability test provided complementary observations regarding the ability of feed formulations to maintain their structural form during immersion. Figure 2 presents the average time required for feed samples to lose their original shape in water under the same treatment combinations. In the control treatment (without binder), shapeless feed occurred after approximately 5 minutes for all treatments, confirming the weak structural integrity of feed without binders.

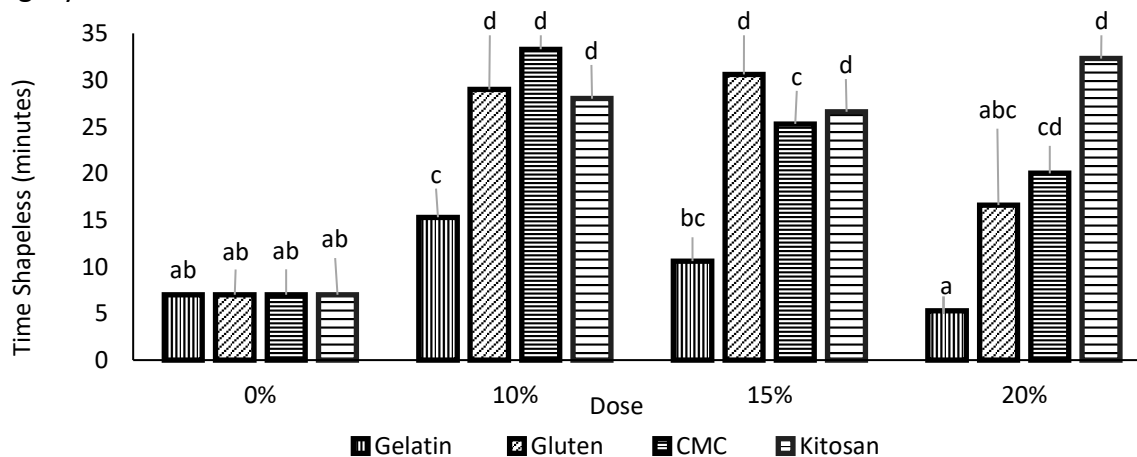


Figure 2. Feed Shapeless Time

Considering binder use efficiency, the 10% inclusion level was the most optimal compared to the 15% and 20% levels in terms of feed stability.

Feed Acceptance

Table 2 presents the observed feeding responses under five feed treatments: control, gelatin, gluten, CMC, and chitosan. The control treatment produced high in number of eels approaching feed, with a total of 15 observations followed by gelatin and gluten, CMC and Chitosan. However, actual feed consumption patterns differed from approach behavior. Gluten treatments recorded the highest number of eels consuming feed, followed by gelatin. The control treatment and both CMC and chitosan treatments recorded 6 individuals consuming feed. These findings indicate that although control feed attracted more approaches, binder-treated feeds improved feeding persistence and consumption.

Feed rejection behavior also differed among treatments. In the control group, 2 eels spat out the feed after initial contact, whereas gelatin and chitosan treatments recorded no rejection behavior. The lower rejection rates in gelatin and chitosan treatments suggest that these binders may improve feed texture and palatability without negatively affecting feeding behavior. Refusal behavior was highest in the control treatment. These results support the hypothesis that feed formulation and binder inclusion influence feeding acceptance among eels.

Table 2. Eel Behavioral Responses to Feed with Different Binder Treatments

Parameters	Control	Gelatin 10%	Gluten 15%	CMC 15%	Chitosan 20%
Approaching feed (fish)	15	14	14	11	11
Consuming feed (fish)	6	8	9	6	6
Spitting out feed (fish)	2	0	1	3	0
Refusing feed (fish)	8	6	5	5	5

The sequence in which feed treatments were consumed provides additional insight into eel feeding preference. Table 3 presents the order of feed consumption observed during feeding trials.

Table 3. Frequency of Feed Consumption Based on Selection Order During Feeding Trials

Feed Sequence	Control	Gelatin 10%	Gluten 15%	CMC 15%	Chitosan 20%
First consumed	3	4	4	3	4
Second consumed	1	4	4	2	1
Third consumed	0	0	1	1	1
Fourth consumed	2	0	0	0	0
Fifth consumed	0	0	0	0	0

Gluten, gelatin, and chitosan treatments were most frequently consumed first, each being selected four times during feeding observations. Second feeding positions were dominated by gelatin and gluten treatments. The third, fourth, and fifth feeding positions occurred rarely across treatments; however, only the control treatment was recorded twice as the fourth feed consumed, while the other treatments were not observed.

Figure 3 presents the average feeding latency observed across treatments. The time required for feed consumption ranged between approximately 6 minute and 15 minutes. Shorter feeding latency indicates greater feed attractiveness, while longer latency suggests reduced palatability or exploratory hesitation. Based on the results of the Kruskal–Wallis test, the time required for the feed to be consumed did not differ significantly among treatments ($p > 0.05$). This result indicates that differences in binder type did not significantly affect the time required for eels to consume the feed when no alternative feed options were available.

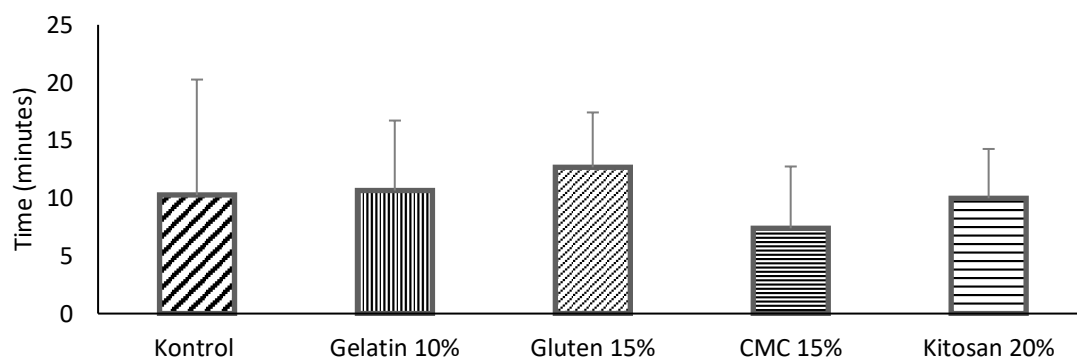


Figure 3. Time Required for Eels to Approach and Consume the Feed

DISCUSSION

The feed stability results obtained in this study indicate that the incorporation of binding agents plays a critical role in maintaining the structural integrity of aquaculture feed during immersion. As shown previously in Figure 1, treatments containing binders demonstrated substantially greater resistance to feed disintegration compared with the control treatment without binders. Among the evaluated treatments, the 10% chitosan treatment showed the highest resistance to feed breakage. This result suggests that chitosan effectively improved adhesion among feed particles, producing a compact and cohesive feed structure capable of resisting mechanical disruption when exposed to water. These results confirm previous

findings showing that chitosan as a binder produced better feed stability compared to gelatin and gluten (Abidin *et al.*, 2025b).

In contrast, the control treatment exhibited the lowest feed stability because it lacked a binding material capable of strengthening the feed matrix. Without a binder, feed particles rely primarily on mechanical compaction and moisture cohesion, which are insufficient to maintain structural integrity during immersion. Consequently, the feed rapidly disintegrated in water, leading to fragmentation and dispersion of feed particles. Similar observations have been reported in previous aquafeed formulation studies, where feed lacking adequate binders demonstrated rapid breakdown and increased nutrient loss due to leaching (Abidin *et al.*, 2025b; Kabir *et al.*, 2025; Karim *et al.*, 2022). This outcome highlights the importance of incorporating suitable binding agents in aquaculture feed formulations to maintain feed quality and prevent the rapid dissolution of nutrients in the culture environment.

Based on the results of this study, a binder concentration of 10% produced similar feed stability to that of the 15% concentration, while stability tended to decrease at higher concentrations. A similar decline in feed stability was also reported by Ighwela, Ahmad, and Abol-Munafi (2014) who found that increasing the inclusion level of maltose as a binder reduced pellet stability. Higher binder concentrations may alter the interactions among feed ingredients, resulting in a less compact pellet structure and greater water absorption (Tacon & Metian, 2015).

Among the binders tested, chitosan produced good feed stability. In addition to functioning as a binder, chitosan is also known to have beneficial effects as an immunostimulant in fish, enhancing immune responses and improving fish health (Ihsan *et al.*, 2025; Harris *et al.*, 2025).

Behavioral observations conducted during the feeding trials revealed important relationships between feed formulation and eel feeding responses. As shown previously in Table 2, the control treatment attracted the highest number of eels approaching the feed. This pattern is likely associated with the strong natural odor of earthworms included in the feed mixture. Earthworms are widely recognized as natural attractants in eel culture because they release chemical cues that stimulate feeding behavior in carnivorous fish species (Sintiya *et al.*, 2025). Olfactory signals produced by natural prey items can significantly increase feeding motivation by activating chemosensory receptors responsible for detecting food in aquatic environments.

Despite attracting more initial approaches, the control treatment also produced the highest level of feed rejection. This phenomenon may be explained by the rapid physical breakdown of the feed once immersed in water. Because the control feed lacked binding agents, its structure deteriorated quickly, making it difficult for eels to grasp or consume the feed effectively.

The results showed that the time required for eels to approach and consume the feed ranged from approximately 6 to 15 minutes across treatments. Feeding latency is often used as an indicator of feed attractiveness and palatability. Shorter feeding latency generally reflects higher feed attractiveness and stronger feeding motivation in fish (Conti *et al.*, 2023; Hattori *et al.*, 2024).

In the present study, the relatively similar feeding latency among treatments suggests that the addition of different binders did not substantially alter the sensory characteristics of the feed that could affect eel feeding behavior. This indicates that the attractant component in the feed formulation likely played a more dominant role in stimulating feeding responses than the binder type.

Binders are primarily included in feed formulations to improve the physical quality of pellets, such as durability and water stability, rather than to enhance feed palatability, sebagai contoh pada binder CMC (Yusoff *et al.*, 2021), meskipun demikian beberapa penelitian menunjukkan bahwa binder dapat meningkatkan tingkat penerimaan pakan (Abidin *et al.*, 2025b; Ihsan *et al.*, 2025; Kabir *et al.*, 2025; Karim *et al.*, 2022).

In addition, the absence of alternative feed choices in this experiment may also explain the lack of significant differences in feeding latency. Under single-feed conditions, fish tend to consume the available feed regardless of minor variations in feed characteristics. Consequently, the feeding response observed in this study likely reflects the general acceptance of the feed rather than a preference influenced by binder type.

CONCLUSION

The results of this study demonstrate that the incorporation of binders significantly improves the physical stability of artificial pasta feed for swamp eel (*Monopterus albus*) compared with feed without binders. Among the tested binders, chitosan showed the best performance in maintaining feed integrity, particularly at the 10% inclusion level, which provided the highest resistance to feed breakage during water immersion. Increasing binder concentration beyond this level did not further improve feed stability and in some cases tended to reduce pellet integrity, indicating that excessive binder inclusion may negatively affect feed structure.

In terms of feed acceptance, binder type did not significantly affect feeding latency or overall feed acceptance by eels. These findings suggest that optimizing binder type and concentration, particularly the use of chitosan at moderate levels, can enhance feed stability without negatively affecting feeding responses, thereby supporting the development of more stable and efficient artificial feeds for swamp eel aquaculture.

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